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Analysis of the Impact of Urban Wetland on Urban Temperature Based on Remote Sensing Technology

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Abstract

The typical urban wetland—Xixi wetland was selected as the object of study. The regulation of urban wetland on urban temperature was analyzed quantitatively and qualitatively using Landsat TM remote sensing image of Hangzhou in July 8 th, 2000、July 26 th, 2004 and Aug 12th 2010. The result shows that urban wetland has good regulation on urban temperature, and the closer to urban wetland the regulation on temperature will be more remarkable. The regulation range and extent of urban wetland on urban heat island may vary due to the types of wetland

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Keywords: urban wetland; urban temperature; image; impact; Hangzhou

1. Introduction

The theme of World Wetlands Day 2010 is wetland, biodiversity and climate change. During the past century, Earth's climate has undergone a significant global climate change with global warming as the major feature [1]. Urban climate is a local climate formed by the impact of the particular underlying surface and human activities of cities at the background of regional climate [2]. Since 1818 L. Howard found that the temperatures in the urban districts of London were higher than the rural areas, scholars from various countries have been observing many cities. Song Dynasty, the famous poet Lu You wrote "urban remaining dog day heat, Autumn first wild people," in one of his poem, describing the phenomenon of urban heat island effect. However, urban expansion reduces the natural underlying surface and weakens the curb of the natural ecology on the heat island [3]. Wetland contains a large amount of water by nature, and it is a type of underlying surface. The radiation process among atmosphere, vegetation and soil surface, exchange of sensible and latent heat, heat transfer of thermal conduction between soil and soil

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pore space occurring in the wetland energy conversion may all directly or indirectly affect the climate and environment [4]. Among them, the cooling effect of wetland directly or indirectly affects the surrounding environment and climate, which is conducive to improving the micro climate of local urban areas and weakening the urban heat island effect [5]. Urban wetland refers to the coast and estuarine, riverbank, shallow lakes, water source protection areas, natural and artificial ponds, and sewage treatment systems within the urban areas, which is a land and water ecosystem with the transitional nature [6].

The key of wetland research is to obtain information and analyze wetland information quantitatively (including information of time and space), and the development of remote sensing technology provides a new technological means and methods for various work about wetland [7]. Currently, information sources used to study the thermal infrared remote sensing are the fourth channel (10.5μm-11.3μm) and the fifth channel (11.5μm-12.5μm) of meteorological satellite AVHRR from NOAA, and the sixth wave band (10.4μm -12.5μm) of landsat TM. As the image resolution of TM is 120 m, much higher than the NOAA satellites, it is more effective for the study of the landscape of thermal field dynamics [8]. At present, very few people in our country use remote sensing technology to study the impact of wetland on urban air temperature.

The past 20 years has witnessed a significant rising of the average temperature in Hangzhou. During 2003-2006, up to 40-50 days of continuous high temperature appeared in the summer of Hangzhou, which made it one of the cities with the highest temperature in summer of China [5]. Xixi Wetland is a rare urban secondary wetland in China, and it serves with the West Lake with similar functions and complements each other, which are both the most important ecological resources in Hangzhou. Through a case simulation study and statistical analysis, Zhang Lifeng et al [3] found that if the control areas of Xixi wetland including the surrounding landscape regain to 50 square kilometers, the maximum temperature of urban areas can be reduced by1.0 ℃ at most

2. Data sources and research methods

Data sources. The typical urban wetland—Xixi wetland was selected as the object of study. The regulation of urban wetland on urban temperature was analyzed quantitatively and qualitatively using Landsat TM remote sensing image of Hangzhou in July 8 th, 2000, July 26 th, 2004 and Aug 12th 2010 combined with previous research of the sixth band image, that is, the impact of thermal infrared on surface temperature.

3. Research Methods

T **Impact algorithm of surface temperature.** Landsat TM data has only one channel ---- thermal infrared channel, that is, the 6-band data (10.3-12.5 m) has recorded the infrared light emitted by the earth's surface, thus owning a relatively high spatial resolution and being able to impact the surface temperature more accurately. There are generally 4 methods to utilize the TM / ETM + thermal infrared channel to impact surface temperature, including radioactive transfer equation, the impact algorithm based on image, single-window algorithm and single-channel algorithm. The impact algorithm based on image is simple, which only considers the impact of surface emissivity rather than its dependency on foreign parameters. While Single-window algorithm and single-channel algorithm consider both the impact of surface emissivity and the impact of atmospheric radiation, moreover, their overall trends are close. Single-channel algorithm requires 2 parameters--- surface temperature and atmospheric moisture content, while the single-window algorithm only needs the latter [9], thus this article applied the single- window algorithm proposed by Qin Zhihao [10] to estimate the land surface temperature for 6 band of TM. The formula is:

$$Ts = \frac{1}{C}\left\{a\left(1-C-D\right)+\left[b\left(1-C-D\right)+C+D\right]T\text{sensor}-DTa\right\}. \qquad (1)$$

Among them, C = ετ, D = (1-τ) [1 + (1-ε) τ], a =- 67.355351, b = 0.458606, ε is surface emissivity, τ is the transmittivity of the entire atmosphere, Tsensor is the brightness and temperature of the sensor, *T*a is the average temperature of the atmosphere. The formula is shown as follows:

Ta=16.0110+0.92621T0 (2)

Among them, T_0 is the atmospheric temperature of the surface layer. The atmospheric transmittivity was estimated according to atmospheric water vapor content and the formula is shown as follows:

τ=0.974290-0.08007w(high temperature, 35 °) (3)

τ=0.982007-0.09611w(low temperature，18°) (4)

Among them, w is the atmospheric water vapor content and the calculating model is:

w(z) = Rw(z) (5)

Among them, w (z) is the atmospheric water content (g/cm^2)at the height of z; in the surface layer, $R_w(0)$ is approximately equal to 0.40206, so the atmospheric water vapor content W can be calculated according to the air humidity of the surface layer.

Surface emissivity in this paper is calculated according to the algorithm proposed by Zhang Zhaoming [11]. First, monitor and sort the research area, and then use the maximum likelihood method to divide the image into buildings, natural surfaces and water. Finally according to the classification results, calculate the surface emissivity ε using NDVI.

For water body, ε = 0.995;For the natural underlying surface, the formula is shown as follows:

$$\varepsilon = P_V r_V \varepsilon_V + (1-P_V) r_S \varepsilon_S + d\varepsilon \qquad (6)$$

Among them, P_V is the proportion of vegetation accounting for mixed pixel, rs and rv are respectively the temperature ratio of vegetation and soil, εv and εs are the emissivity of vegetation and soil. Take εv = 0.986, εs = 0.972.

$$r_V = 0.933 + 0.059P_V \qquad (7)$$

$$r_S = 0.990 + 0.107P_V \qquad (8)$$

dε is the contribution of surface emissivity due to the interactive radiation effect of vegetation and bare soil, and its formula is estimated by the following empirical formula:

When $P_V \le 0.5$,

$d\varepsilon=0.0038P_V$ (9)

When $P_V > 0.5$,

$d\varepsilon=0.0038(1-P_V)$ (10)

When $P_V=0.5$, dε reaches maximum, dε=0.0019

PV can be calculated by the following formula:

$$P_V = \left[\frac{NDVI - NDVI_{min}}{NDVI_{max} - NDVI_{min}}\right]^2 \qquad (11)$$

$NDVI_{max}$, $NDVI_{min}$ are the NDVI values of the complete vegetation area and complete non-vegetation area . Take the approximate values as 0.70 and 0.05.

If NDVI> $NDVI_{max}$，then take P_V=1

If NDVI<$NDVI_{min}$，then take P_V=0

For building area, the formula is shown as follows:

$$\varepsilon = P_V r_V \varepsilon_V + (1-P_V) r_m \varepsilon_m + d\varepsilon \qquad (12)$$

Among them, r_m is the temperature ratio of the surface of building area; ε_m the emissivity in the surface of buildings. Take εm as 0.970, and the algorithm of dε is similar to what has been mentioned above.

$r_m=0.998+0.128P_V$ (13)

Data Processing and Analysis. Obtain the inversion chart of surface temperature (Figure 1) through the above process. On this basis, regard the average temperature outside the city as the reference value and then conduct the margin calculations to draw anomaly chart of surface temperature (Figure 2) in order to reveal the distribution of heat island intensity in Hangzhou. Finally, by means of analyzing the capabilities of GIS buffer, regard the Xixi Wetland boundary as a starting point to set the buffer area of 500m with the uniformly-distance of 50 m and record the mean surface temperature in different buffer distances (Figure 3). Calculate the thermal regulation index at different distances of wetlands (Figure 4) in order to analyze the regulation of urban wetland on urban temperature.

Wetland thermal index (WTI）is defined as：

$$WTI=\frac{T_1-T_2}{T_1} \tag{14}$$

Among them, T_1 is the average surface temperature in urban districts and this study selected the mean surface temperature in urban district main of Hangzhou as T_1; T_2 is the average surface temperature after wetland regulation. The greater WTI is, the more remarkable the thermal regulation of urban wetlands will be, and vice versa.

4. Results and Analysis

Spatial Analysis of Urban Heat Island

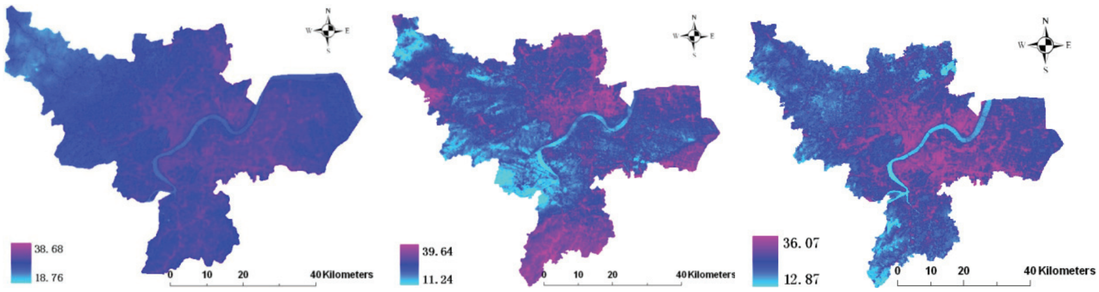

Fig.1 The inversion map of surface temperature in Hangzhou in the afternoon on July 8th 2000， July 26th 2006 and Aug 12th 2010

Figure 1 shows that surface temperature in summer of Hangzhou tends to increase from west to east. The temperature reaches its highest point in the urban district and Xiasha, while there are also high temperature zone in Linping and Xiaoshan. This distribution is basically consistent with the vegetation cover and the divisions of functional areas in Hangzhou, that is, the vegetation cover in Hangzhou decreases from west to east with the lowest vegetation cover and most urban construction and other non-natural cover in the main city zone. On the one hand, vegetation can absorb CO_2 and CH_4 and other greenhouse gases, which are the important factors that cause temperature rising; on the other hand, high-density urban buildings and high-rise buildings are greatly connected with heat distribution. The thicker the building density, the more easily the heat gathers and the greater the intensity. This is caused by concentration of heat and it is not easy to distribute, which, to some extent, contributes to the inclination to heat up and difficulty in cooling down in city district. In the figure, the maximum surface temperature in 2004 was close to 40 ℃, 10 ℃ higher than urban wetland areas, and gradually weakened from the main city to areas around. The high temperature range further expanded in 2010 and a sign of heat had already appeared in the west of the city. Areas that were concentrated in vegetation and water substance in Qiantang River, Xixi wetland, and West Lake showed relatively low temperature, and air flow was bound to spread the cold gas in the wetland, which produced a cooling effect on its surroundings

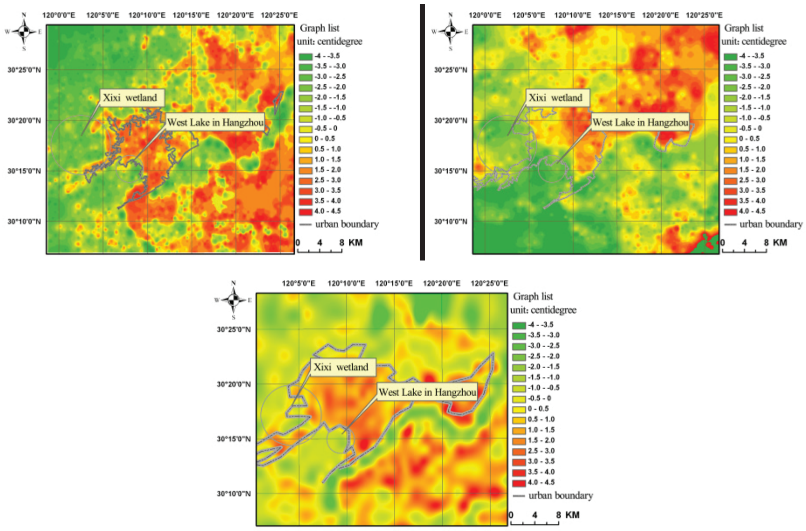

Fig.2 The departure map of surface temperature in Hangzhou in the afternoon July 8th 2000，July 26th 2006 and Aug 12th 2010

Figure 2 describes the difference between the surface temperature and the average surface temperature in suburban district. Compared with Figure 1, it has directly revealed the distribution of heat island intensity. It is obvious that the heat island intensity of the main city and Xiasha is up to 4.0 ~ 4.5 ℃ and diverge outward with a gradual weakening trend, which is as low as -4 ~ -3.5 ℃ in the rural and western areas of more vegetation. Strong heat island intensity in Xiasha, Xiaoshan and other regions outside the main city is mostly distributed on Xiasha Economic and Technological Development Zone, Xiaoshan Economic and Technological Development Zone and Xiaoshan Airport. This is because the city buildings, roads, squares, bridges, land use built of cement and tile structure, the composition of the urban factor, are the dominant components that constitute high temperature zone [8]. Also large populations in these areas, relatively serious air pollution caused by industrialization and the fact that air pollutants can absorb long-wave radiation and reduction of surface solar radiation caused by contamination [12] increase the temperature, and thus they are conducive to the formation of heat islands. It can be seen from the figure that in 2004, the heat island intensity in Xiasha is stronger than that in the main city, which may be due to the followings: 2004 is a “year of relocation” for colleges and universities in Hangzhou. Zhejiang University of Technology and Science, Zhejiang Institute of Finance, Hangzhou, Zhejiang Institute of Media and other fourteen colleges and universities moved to Higher Education Campus in Xiasha, which rapidly increased a lot of dry and impervious building materials appeared in the school buildings, shops, dining places, etc. Surface albedo expresses the reflectivity of underlying surface on the sun's radiation, which is closely related to the nature of the underlying surface. In the process of urbanization, the natural underlying surface has been replaced by artificial buildings and structures, making the urban surface albedo decrease. If albedo increases by 0.14, it will help to reduce the summer heat by 1.5 ℃ [13]. In addition, Xiasha is a new city zone, and most of the buildings are quite new. However, its urban greening and other facilities are lagging behind, unable to alleviate the urban heat island effect accordingly, and this may result in more obvious heat island intensity in Xiasha than in the main city.

Analysis on the regulation of urban wetland on the urban heat island. As a kind of natural underlying surface, wetland is full of water and vegetation. Besides the albedo of water is relatively large, so the plants can convert a lot of luminous energy to potential in order to weaken the effect of solar radiation, therefore, vegetation can effectively reduce surface temperature [14]. As shown in Figure 2, the temperature of Xixi wetland and the west lake is relatively low. The heat island intensity gradually decreases from the periphery to the urban area of Xixi Wetland, indicating that the closer it is to the wetland, the more remarkable the cooling effect will be. Similarly, the tendency of this kind of temperature changing also can be seen around the West Lake and it will get quantitative analysis and verification in the following part.

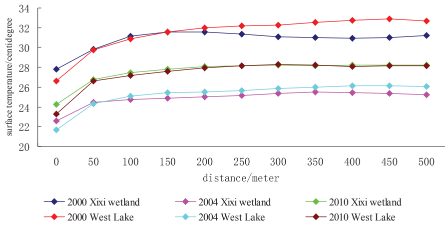

Fig.3 Land surface temperatures in different buffer radius of urban wetland

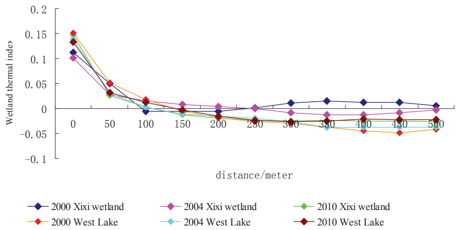

Fig.4 Wetland thermal index in different buffer radius of urban wetland

Figure 3 and Figure 4 show that the average temperature of Xixi wetland and West Lake is lower than that of farthest edge of the buffer area in 2000 with the D-value of 3.38 ℃ and 5.08 ℃, while the D-value is 2.64 ℃ and 4.44℃ in 2004, in 2010 the D-value is 3.96 ℃ and 4.85 ℃. The thermal regulation index of wetlands is gradually decreasing, which has quantitatively validated the variation tendency of surface temperature shown in Figure 2, that is, from the wetland boundary to the outside of wetland, the more distant the buffer zone is away from the wetland, the greater the average surface temperature and the weaker the regulation of wetland. The analysis on the variance of these 3 years tells us that the more distant Xixi wetland and buffer zone of West Lake is, the larger the standard deviation, which indicates that the greater the variation of the thermal environment will be. In addition, the standard deviation in 2010 is less than that in 2000 and 2004, which may be because that the temperature has gradually decreased since August and the urban heat island effect will be alleviated, thus the effect of distance from the wetland on the surface temperature may be reduced. It can be seen from the figure that the average surface temperature from the inside of Xixi wetland and West lake to the 50m buffer takes on a very significant climbing, about 2.5 ℃, while the average surface temperature at 300 m and beyond 450m tend to be stable, which to some extent help us see the scope and the level of regulation of urban wetland on the temperature

5. Conclusion and discussion

This paper qualitatively analyzed the distribution of heat island in Hangzhou using Landsat TM remote sensing image of Hangzhou in July 8 th, 2000, July 26 th, 2004 and Aug 12th 2010 combined with the algorithm to impact the surface temperature. Then it carried on a qualitative analysis on the regulation of urban wetlands on the urban temperature respectively using Hangzhou heat island intensity anomaly map, the surface temperature map of different buffer radius of urban wetlands as well as index map of wetlands thermal regulation. The result shows that urban wetland has good regulation on urban temperature, and the closer to urban wetland, the more remarkable the regulation on temperature will be. The regulation range and extent of urban wetland on urban heat island may vary due to the types of wetlands, such as the proportion and distribution pattern of water in urban wetlands, vegetation and other landscape types, which still need future research.

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ZHU Wei-ping is the corresponding author..

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